DERIVATION OF SURFACE FLUXES WITHIN ONE WEEK OF SATELLITE MEASUREMENTS USING THE FLASHFLUX ALGORITHMS

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ABSTRACT

For over a decade the Clouds and the Earth's Radiant Energy Systems (CERES) project has been drawing together measurements to produce a world-class climate data record. Obtaining the very highest degree of accuracy needed for climate analysis, however, requires processing that typically delays the availability of the CERES results to the climate community by more than six months after the satellite measurements. Although such delays are not critical for climate studies, there are a number of near real-time uses for the CERES data. Thus, the Fast Longwave and Shortwave Radiative Flux (FLASHFlux) endeavor was envisioned as a program that would exchange some accuracy for speed and thereby gain the ability to derive surface fluxes within one week of satellite measurements. The FLASHFlux endeavor not only achieved this one-week goal, but has also derived results that compare very favorably with the CERES results.

Index Terms— FLASHFlux, CERES, SSF, TISA

1. THE FLASHFLUX PRODUCT

Defining the radiative energy exchange at the top of the Earth-atmosphere system and at the Earth's surface has long been identified as critical to understanding climate processes [1][2]. Whereas the top-of-atmosphere (TOA) radiative energy exchange represents the response of the entire Earth-atmosphere system to changes in the total solar irradiance (TSI), reflected shortwave (SW) and outgoing longwave (LW), the surface energy budget represents the energy exchange between the atmosphere and the Earth-surface driven by radiative, sensible and latent heating processes. Accurate derivations of the TOA and surface radiative quantities allows for closure in the atmospheric radiative budget and improvement in the calculations of the inferred heat transports within the Earth-atmosphere system. The SW and LW net surface fluxes affect the heating/cooling of the surface and as such provide bounds for sensible and latent heat fluxes, as well as estimates for the horizontal oceanic and atmospheric heat transport. Changes to the input energy into the surface systems affect short and long-term weather and climate related processes. Changes to cloudiness, aerosols, and gaseous profiles regulate the TOA and surface fluxes and as such ultimately impact the Earth's energy balance and climate. Even changes to the surface reflective/emissive properties, such as those caused by evolving land use or ice/snow coverage can have profound effects on net surface fluxes resulting in important regional feedbacks. For these reasons, quantifying the surface radiative fluxes through changes to surfaces and atmospheric state constitutes an important step in understanding the processes relating weather variability and climate variations.

Even as the satellite measurements were being used to retrieve surface fluxes and estimate changes in the Earth's energy balance, there was becoming an ever-increasing recognition of the need to have access to the surface and TOA radiative properties closer to the time of the TOA measurements. Nevertheless, since the emphasis was on the production of high quality fluxes for climate research, until the formulation of the FLASHFlux (Fast Longwave and Shortwave Flux) product every major global TOA and surface radiation dataset had been produced six months to several years after the actual satellite overpass. The importance of deriving TOA and surface radiative fluxes in near real-time has become increasingly evident in studies, such as Kay et al. 2008 [3], where differences in the net surface radiative fluxes of 28 Wm^{-2} between the years 2007 and 2008 for the western Arctic were shown to be associated with a reduction of clouds and sea ice amounts for that region during the summer of 2007.

The FLASHFlux endeavor was undertaken to develop an operational system that uses existing CERES processing techniques to derive global near real-time radiative fluxes for the TOA and surface [4]. The FLASHFlux product uses satellite data from a number of sources to calculate the SW and LW surface fluxes. Primary among these sources is the measurement of TOA radiances provided by the CERES instrument in three broadband channels: Total (0.2 to 100 μm), SW (0.2 to 5 μm) and infrared window (8 to 12 μm). The FLASHFlux endeavor takes advantage of the algorithms developed for the CERES project to invert the TOA radiances into SW, LW (5 to 100 μm) and infrared window fluxes. Unlike CERES, however, FLASHFlux does not wait for precisely calibrated spectral response functions and gains (SCC) to be deduced from the CERES measurements, but instead uses the best estimate of the SCC values from data available at the time of measurement [5]. By not waiting for the latest SCC results, the FLASHFlux processing can be expedited to provide the user with near real-time data. In addition to the CERES TOA data, FLASHFlux also incorporates the temperature and humidity profiles provided by the Global Modeling and Assimilation Office (GMAO) Goddard Earth Observing System (GEOS). Again, unlike the CERES project, which emphasizes algorithmic stability, the FLASHFlux endeavor does not depend upon a static assimilation for the temperature and humidity data, and thus, is able to use the latest release of the GMAO-GEOS datasets [6] [7]. These upgrades, however, will produce occasional discontinuities, and thus, care must be taken not to misinterpret the upgrades in the input datasets as climate signals. The FLASHFlux endeavor obtains the ozone amounts through the National Centers for Environmental Prediction–Stratosphere Monitoring Ozone Blended Analysis (NCEP–SMOBA) [8]. Fractional cloud amount and cloud-base height have been derived using the CERES processing strategy [9]. This strategy relies upon high-resolution imager data from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument [10].

To obtain global coverage, FLASHFlux uses the all-sky surface flux algorithms from the CERES project [11]. These algorithms, in conjunction with the TOA quantities, are used to produce surface fluxes from satellite measurements within 4 days for the footprint product and within 6 days for the 1° × 1° gridded daily product. Thus, the FLASHFlux program has been able to provide reliable estimates of the TOA and surface radiative properties over the entire globe in the near real-time observation period and certainly well before the production of the climate-quality CERES flux results, which typically are made available some 6 to 12 months after the observations. Beyond the assimilation and processing of the various datasets, the FLASHFlux endeavor has been designed with the capability to analyze the magnitudes and variability of these quantities on global and regional scales.

The near real-time fluxes produced by the FLASHFlux effort satisfy the critical needs of organizations that require higher degrees of accuracy than provided by synoptic weather forecasting datasets but whose operation are unable to wait for the climate quality datasets provided by systems such as CERES. Thus, the FLASHFlux effort can contribute significantly to satellite data analysis from programs such as CloudSat and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO), experimental and operational field programs, ocean and land assimilation efforts, energy and agricultural applications, near real-time climate analysis studies, and education and public outreach programs. FLASHFlux has also provided a prototype operational system that can be applied to upcoming satellite programs such as Joint Polar Satellite System (JPSS).

2. VALIDATION RESULTS

Figure 1 illustrates the comparison of the FLASHFlux model-derived LW all-sky surface fluxes retrieved using the Terra and Aqua TOA measurements for the years 2009 and 2010 with the corresponding radiometric data obtained directly from the surface validation sites. The overall systematic difference between these data sets is quite small, -3.8 Wm^{-2}, while the overall random difference, 24.5 Wm^{-2}, is similar to past studies [12], and reflects the challenging nature of retrieving all-sky conditions. Indeed, if only clear-sky cases were to be considered, the random differences would be approximately 40% smaller. The comparisons presented in Table 1 demonstrate that the systematic differences between the FLASHFlux and surface validation results remain small (smaller than ±10 Wm^{-2}) for all scene types. Though the magnitudes of the systematic and random errors for the overall case are disproportionately affected by the contribution of the polar retrievals, which is an artifact of the orbital tracks of the Terra and Aqua spacecrafts. While the 98.2° inclination retrograde orbit for Terra and Aqua yields sun-synchronous equator crossing times, such orbits allow these satellites to view the surface of the Earth through all times of the day over the polar regions, and thus, there are far more coincident data measurements between the TOA and surface instruments for the polar regions. Nevertheless, the LW surface fluxes in the FLASHFlux data product have been found to be of comparable quality to the more exacting CERES data product. Indeed, for all-sky conditions, comparisons of FLASHFlux and CERES results have shown systematic differences that are less than 1 Wm^{-2} and random differences that are less than 7 Wm^{-2}.

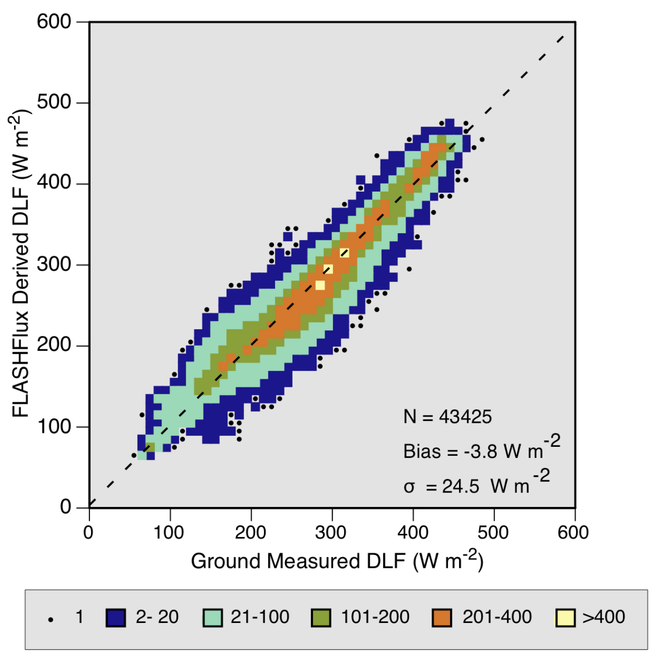

Figure 1. A comparison of the FLASHFlux model-derived LW surface fluxes is based on the Terra and Aqua TOA measurements with the ground-measured LW surface fluxes for all-sky conditions. The plot represents a 2-dimensional histogram that illustrates the number of coincident fluxes found within each 20 Wm^{-2} square bin. The legend defines the number of values in each bin.

Type	FLASH		FLASH minus Ground	
	n	Mean (Wm^{-2})	Bias Wm^{-2} (%)	σ Wm^{-2} (%)
Isl	3266	409.9	5.4 (1.3)	14.2 (3.5)
Coa	3004	340.8	-0.7 (-0.2)	16.3 (4.8)
Pol	21081	224.7	-3.6 (-1.6)	25.0 (11.2)
Con	11820	311.1	-8.0 (-2.6)	23.2 (7.4)
Des	4254	326.3	-2.4 (-0.7)	17.1 (5.2)
All	43425	280.6	-3.8 (-1.4)	24.5 (8.7)

Table 1. A comparison of the FLASHFlux model-derived LW surface fluxes is based on the Terra and Aqua measurements with the surface-measured fluxes for all-sky conditions. The columns represent: the surface type (Type); where Isl is Island, Coa is Coastal, Pol is polar, Con is Continental, Des is Desert, and All is the sum of all types; the number of measurements (*n*); the mean values of the FLASHFlux model-derived fluxes (Mean); the systematic differences [FLASHFlux minus surface-measured (Bias)]; and the random differences (σ). For the systematic and random differences, percentage differences are provided in parentheses in addition to the flux values.

Figure 2 illustrates the comparison of the FLASHFlux model-derived SW all-sky surface fluxes retrieved using the Terra and Aqua TOA measurements for the years 2009 and 2010 with the corresponding radiometric data obtained directly from the surface validation sites. The overall systematic differences between these data sets is quite small, 1.3 Wm^{-2}; however, this is due in part by a cancellation of large offsetting differences within and among the various surface sites. Indeed, the overall random difference is fairly substantial, 85 Wm^{-2}, reflecting the very challenging nature of retrieving individual SW measurements for all-sky conditions [13,14]. As with the LW surface fluxes, the SW surface fluxes in the FLASHFlux data product have been found to compare favorably to the more exacting CERES data product. Indeed, for all-sky conditions, comparisons of FLASHFlux and CERES results have shown systematic differences that average less than 3 Wm^{-2} and random differences that are less than 16 Wm^{-2}.

Even though the individual LW and SW results from FLASHFlux compare very favorably with their CERES counterparts, care must be taken not to mix the two data products. CERES is a climate data record, which depends on the stability of both the input dataset as well as the processing algorithms. Changes to either could result in a spurious effect that could be misinterpreted as a climate signal. In contrast, FLASHFlux is an environmental data record, which is continuously improved by incorporating both algorithmic upgrades and revised input datasets. No attempt has been made to ensure long-term stability since FLASHFlux was designed for near real-time use rather than long-term datasets.

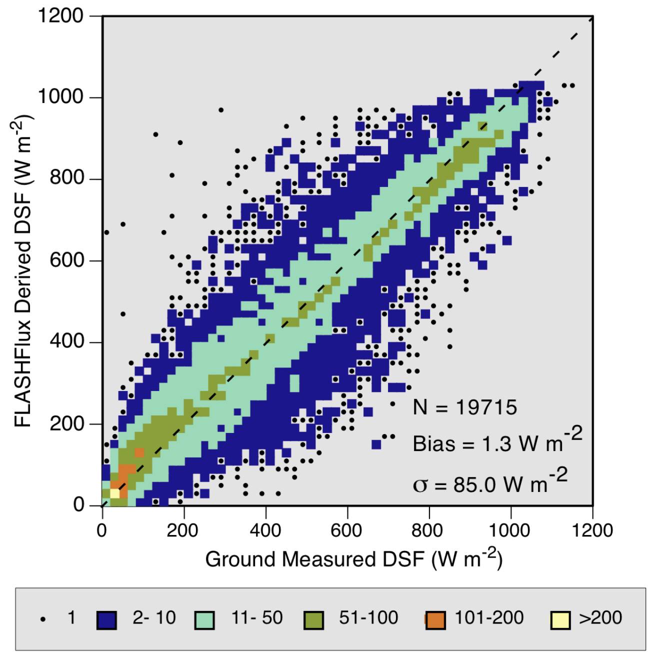

Figure 2. Same as Figure 1 except that the FLASHFlux model-derived SW surface fluxes are compared with the ground-measured SW surface fluxes for all-sky conditions.

Type	FLASH		FLASH minus Ground	
	n	Mean (Wm^{-2})	Bias Wm^{-2} (%)	σ Wm^{-2} (%)
Isl	1656	661.1	40.3 (6.1)	103.1 (15.6)
Coa	1475	535.4	22.9 (4.3)	60.6 (11.3)
Pol	8538	243.7	-8.5 (-3.3)	74.7 (30.6)
Con	5937	527.8	2.5 (0.5)	81.6 (15.5)
Des	2109	769.1	-9.9 (-1.3)	72.5 (9.4)
All	19715	442.3	1.3 (0.3)	85.0 (19.2)

Table 2. A comparison of the FLASHFlux model-derived SW surface fluxes is based on the Terra and Aqua measurements to the surface-measured SW surface fluxes for all-sky conditions. The column format is the same as Table 1.

Figure 3 shows daily averaged gridded LW and SW TOA scenes from August 26, 2011. The uppermost image, showing the LW fluxes, indicates that the central core of Hurricane Irene was emitting much less thermal energy to space than the surrounding areas. The lowermost image, showing the SW fluxes, indicates that the central core of Hurricane Irene was reflecting much more solar energy to space than the surrounding areas. Images from the preceding and following days can define the path and the intensity of the storm as it developed and passed near the coastline of the North America.

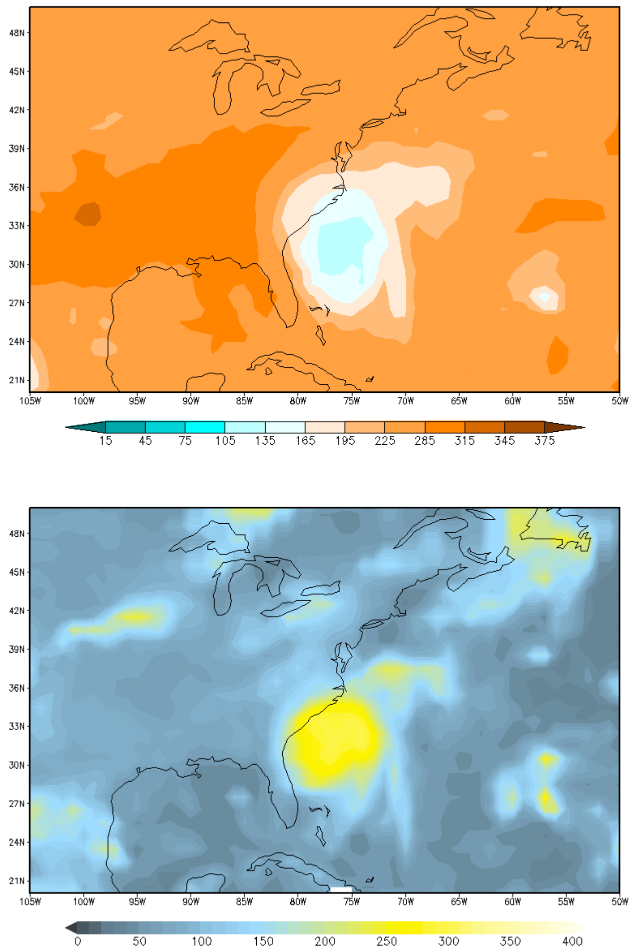

Figure 3. Images derived from FLASHFlux data showing the LW and SW TOA scenes that includes the very cold but highly reflective clouds from Hurricane Irene near the North American coast on August 26, 2011.

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